CHAPTER 12 Review

REFLECTING ON CHAPTER 12

- Oscillators on the surface of a blackbody can oscillate only with specific frequencies. When they emit electromagnetic radiation, they drop from one allowed frequency to a lower allowed frequency.
- The photoelectric effect demonstrated that electromagnetic energy can be absorbed only in discrete quanta of energy. Electromagnetic energy travels like a wave, but interacts with matter like a particle.
- When a photon ejects an electron from a metal surface, the maximum kinetic energy of the electron can be calculated from the equation $E_{k(max)} = hf - W$, where W is the work function of the metal.
- The Compton effect shows that both energy and momentum are conserved when a quantum of light energy, or a photon, collides with a free electron.
- The energy of a photon is $E = hf$.
- The momentum of a photon is $p = \frac{h}{\lambda}$.
- The diffraction of electrons by crystals demonstrated that electrons have wave properties. The wavelength of a particle of matter is $\lambda = \frac{h}{mv}$.
- Physicists accept the dual properties of matter and electromagnetic energy. Electromagnetic energy behaves like particles and particles of matter have wave properties. These concepts are called the "wave-particle duality."
- Dalton believed that atoms were the smallest, indivisible particles in nature. J.J. Thomson demonstrated that electrons could be removed from atoms and, therefore, that atoms were made up of smaller particles.
- By observing the scattering of alpha particles by a thin gold foil, Rutherford demonstrated that the positive charge in an atom must be condensed into an extremely small area at the centre of the atom.
- Bohr proposed that electrons in atoms could exist only in specific allowed energy levels. Electrons in these energy levels are in orbits with specific allowed radii.
- The energies of the photons in the observed spectra of atomic hydrogen have amounts of energy that are exactly equal to the difference in Bohr's allowed energy levels. This fact supports Bohr's concept that electrons can drop from a high energy level to a lower level by emitting a photon.
- Detailed inspection of emission spectra of gases showed that some of the spectral lines are actually made up of two or more lines that are very close together. Also, when placed in an external magnetic field, some single spectral lines split into two or more lines. These data show that Bohr's model of the atom is incomplete.
- Schrödinger's wave equation forms the foundation of quantum mechanics, or wave mechanics. Solutions to the wave equation, called "wave functions," provide information about the properties of electrons in an atom. The operation, $\psi^*\psi$ on the wave function gives the probability that an electron will be found at a specific point in space.
- Dirac modified Schrödinger's wave equation to account for relativistic effects of electrons in atoms travelling close to the speed of light. Wave functions obtained by solving this wave equation contain four quantum numbers. Each quantum number describes one property of electrons that is quantized.
- The Pauli exclusion principle states that no two electrons in the same atom can have the same four quantum numbers.

Knowledge/Understanding

1. Describe how a negatively charged electroscope can be used to provide evidence for the photoelectric effect.
2. (a) Describe the properties of a blackbody and explain how it is simulated in the laboratory.
   (b) How did the actual radiation spectrum emitted by a heated blackbody differ from the predictions of the classical wave theory?
3. The ultraviolet catastrophe was considered to be a flaw in the explanation of the blackbody emission spectra by the classical wave theory. In what way was it unexplained?
4. (a) The results of Lenard's photoelectric experiment partly correlated with the classical wave theory of light. Explain how it agreed.
   (b) In what way did Lenard's results differ from the predictions of the classical wave theory of light?
5. (a) Einstein saw a connection between the photoelectric effect and the Planck proposal that energy be quantized. Explain how Einstein developed an equation to describe the photoelectric effect.
   (b) Einstein's photoelectric equation is actually another example of conservation of energy. Explain how this applies.
6. A lithium surface in a photoelectric cell will emit electrons when the incident light is blue. Platinum, however, requires ultraviolet light to eject electrons from its surface.
   (a) Which of the two metals has a larger value for its work function? Explain your answer.
   (b) Which of the two metals has a higher threshold frequency? Explain your answer.
7. (a) How did a knowledge of the charge on an electron make it possible to calculate the numerical values of the kinetic energies of electrons emitted from a metal surface?
   (b) How did the data from Millikan's photoelectric experiments support Einstein's theory of the photoelectric effect?
8. (a) Explain the sequence by which Compton derived an expression for the momentum of a photon, considering that it has no mass.
   (b) In what way does a photon change "colour" after it has collided with an electron. Is "colour" always a suitable term to use?
9. Based on his premise regarding the momentum of a photon, Compton showed that momentum was conserved in collisions between photons and electrons. As a result, what can be concluded from this experiment?
10. (a) Explain the sequence that de Broglie used in taking Compton's expression for the momentum of a light photon and proposing that particles of matter have a corresponding matter wave and wavelength.
    (b) How can the matter wavelength of a particle be increased to make it more easily detectable?
    (c) Compare (through calculations) the de Broglie wavelength of an electron of mass 9.11×10^{-31} kg, travelling at 3.60 km/h, with that of a hockey puck of mass 0.15 kg, travelling at the same speed.
11. (a) What property of electromagnetic radiation represented a flaw in the Rutherford model of the atom?
    (b) Balmer's equation represents an "empirical expression." What is the significance of this term?
12. In what way did Rydberg modify Balmer's equation?
13. (a) Describe the key features of the Bohr model of the atom, and indicate how this model contradicts classical theory.
    (b) When electrons occupy a higher energy level, what are they likely to do? What options do they have?
14. (a) Write the equation linking the energy of a photon emitted from the Bohr atom to the energy levels of the atom.
    (b) How does this manifest itself in the emission spectrum of an atom?
15. (a) According to Bohr, what property of the electron in its orbit is quantized?

(b) In general terms, explain how Bohr used the equations for Coulomb's law, circular motion, and angular momentum to determine the "Bohr radius."

16. (a) Describe how Bohr used the equations for kinetic energy, Coulomb's law, and the Bohr radius to determine the general formula for the total energy of an electron in a hydrogen atom.
    (b) Explain how the Bohr equation for the total energy of an electron in orbit in a hydrogen atom relates to the observed emission spectrum.
17. (a) Show that the speed of an electron as it moves in an "allowed" orbit can be represented by the equation
$$v_{\mathrm{n}} = \frac{2\pi ke^2}{nh}$$
    (b) Calculate the de Broglie wavelength associated with an electron in the first orbit of the Bohr atom.
18. Schrödinger responded to de Broglie's thesis by developing the Schrödinger wave equation. In what general way did this equation account for the discrepancies in the emission spectra?
19. (a) Do you feel Schrödinger's wave equation is just an abstract model, or is there a "real" significance?
    (b) Discuss whether you believe that the Schrödinger wave functions made the Bohr model obsolete.

Inquiry

20. Schrödinger's wave equation was a famous contribution to what is now called "quantum mechanics." At your library or through the Internet, find and record the exact text of the equation and describe, in general terms, the mathematical operations it incorporated.
21. (a) Research and describe the principle of complementarity.
    (b) Under what conditions does light tend to show its wave properties, and under what conditions does the particle (photon) nature of light predominate?
22. Design and sketch a simple door opener that will open electrically when a person passes through a light beam.

Communication

23. Explain how Lenard was able to determine the maximum kinetic energy of the electrons coming from the emitter of his photoelectric apparatus.
24. (a) Explain how Einstein was able to include the properties of different types of emitter metals in his photoelectric equation.
    (b) Initially, very few physicists accepted Einstein's claim for the quantum nature of light. Why did this opposition exist?
25. Briefly outline the key features of the model of the atom proposed by John Dalton, J.J. Thomson, and Ernest Rutherford.
26. Based on the results of the scattering experiments, Rutherford was led to believe that the atom was mainly empty space with a small charged core. Explain why he deduced this.
27. Some science fiction writers use a large sail to enable a space vehicle to move through space. It is argued that sunlight will exert a pressure on the sail, causing it to move away from the Sun. Prepare a report and/or display in which you indicate
    (a) whether the proposal has merit
    (b) what type of surface should be used for the sail
28. "Wave-particle duality" is a term used to describe the dual properties of both light and particles in motion. Has this meant that Maxwell's equations for electromagnetic wave propagation and Newton's classical mechanics have been discarded? Discuss your opinion.

Making Connections

29. A light meter is used by a photographer to ensure correct exposure for photographs. If the photocell in the meter is to operate satisfactorily up to the red light wavelength of 650 nm, what should be the work function of the emitter material?

30. Some television picture tubes emit electrons from the rear cathode and accelerate them forward through an electric potential difference of 15 000 V.
   (a) What is the de Broglie wavelength of the electron just before it hits the screen?
   (b) Discuss whether you think diffraction of the electron beam might pose a problem with the resulting picture.
31. Prepare a report on laser technology, including reference to the terms “spontaneous emission,” “stimulated emission,” “population inversion,” and “metastable.” In your report, include a reference to the medical applications of lasers.

Problems for Understanding

32. **(a)** The work function for a nickel surface is 5.15 eV. What is the minimum frequency of the radiation that will just eject an electron from the surface?
   (b) What is the general name given to this minimum frequency?
33. **(a)** The longest wavelength of light that will just eject electrons from a particular surface is 428.7 nm. What is the work function of this surface?
   (b) Use Table 12.1 to identify the material used in the surface.
34. When ultraviolet radiation was used to eject electrons from a lead surface, the maximum kinetic energy of the electrons emitted was 2.0 eV. What was the frequency of the radiation used?
35. The electrons emitted from a surface illuminated by light of wavelength 460 nm have a maximum speed of 4.2×10^5 m/s. Given that an electron has a mass of 9.11×10^{-31} kg, calculate the work function (in eV) of the surface material.
36. Assume that a particular 40.0 W light bulb emits only monochromatic light of wavelength 582 nm. If the light bulb is 5.0% efficient in converting electric energy into light, how many photons per second leave the light bulb?
37. **(a)** Calculate the momentum of a photon of light with a wavelength of 560 nm.
   (b) Calculate the momentum of the photons of light with a frequency of 6.0×10^{14} Hz.
   (c) A photon has an energy of 186 eV. What is its momentum?
38. An electron is moving at a speed of 4.2×10^5 m/s. What is the frequency of a photon that has an identical momentum?
39. What is the momentum of a microwave photon if the average wavelength of the microwaves is approximately 12 cm?
40. A particle has a de Broglie wavelength of 6.8×10^{-14} m. Calculate the mass of the particle if it is travelling at a speed of 1.4×10^6 m/s.
41. **(a)** Calculate the wavelength of a 4.0 eV photon.
   (b) What is the de Broglie wavelength of a 4.0 eV electron?
   (c) What is the momentum of an electron if its de Broglie wavelength is 1.4×10^{-10} m?
42. **(a)** Calculate the radius of the third orbit of an electron in the hydrogen atom.
   (b) What is the energy level of the electron in the above orbit?
43. Calculate the wavelength of the second line in the Balmer series.
44. A photon of light is absorbed by a hydrogen atom in which the electron is already in the second energy level. The electron is lifted to the fifth energy level.
   (a) What was the frequency of the absorbed photon?
   (b) What was its wavelength?
   (c) What is the total energy of the electron in the fifth energy level?
   (d) Calculate the radius of the orbit representing the fifth energy orbit.
   (e) If the electron subsequently returns to the first energy level in one “jump,” calculate the wavelength of the corresponding photon to be emitted.